DIRECT PHOTON PRODUCTION AT RHIC

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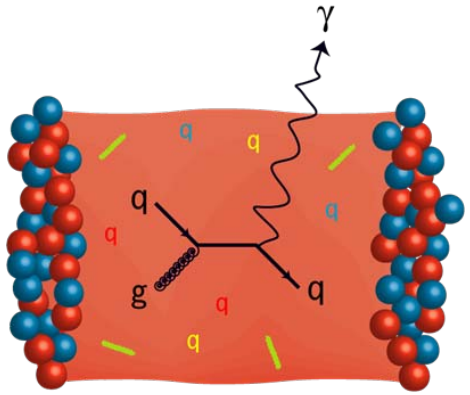
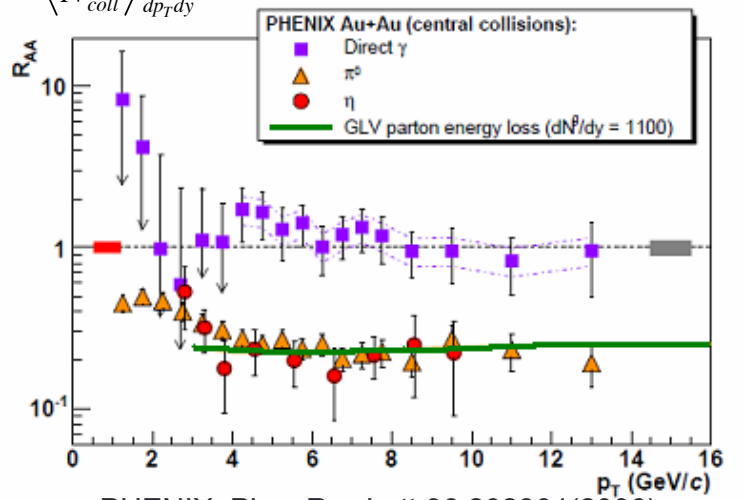
July 24-29th, 2011

Direct photon



$$R_{AA} = \frac{\frac{dN_{AA}}{dp_T dy}}{\langle N_{coll} \rangle \frac{dN_{pp}}{dp_T dy}}$$

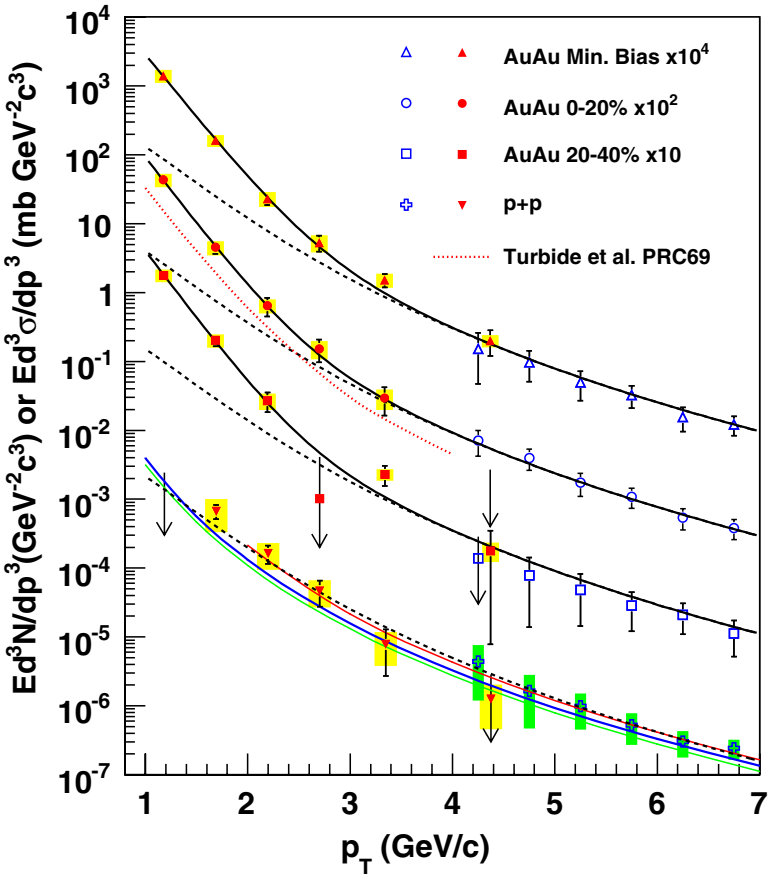


PHENIX, Phys.Rev.Lett.96,202301(2006)

- Direct γ = Inclusive γ – hadron decay γ
- Passes through the medium without the strong interaction
  - High p_T(>5 GeV/*c*): hard scattering (R_{AA}~ 1: N_{coll} scaling works)
  - Low p_T(p_T<3 GeV/*c*): Thermal radiation from hadron and QGP phases (Include fruitful information from QGP)
- Difficulty of measurement
  - Most of measured photons are from hadron decay products.
  - Photons from all stages after collisions are detected.

Direct photon spectra

Centrality dependence of direct photon yield



PHENIX, Phys.Rev.Lett.104,132301(2010)

- p+p
  - Consistent with NLO pQCD
- Au+Au
  - Excess at p_T<3 GeV/*c*
  - Exponential shape (consistent with thermal)
  - Centrality dependence of inverse slope is small.

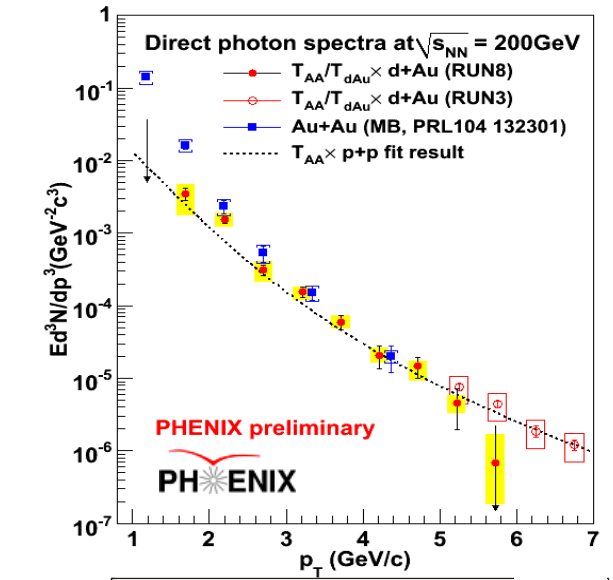
Inverse slope

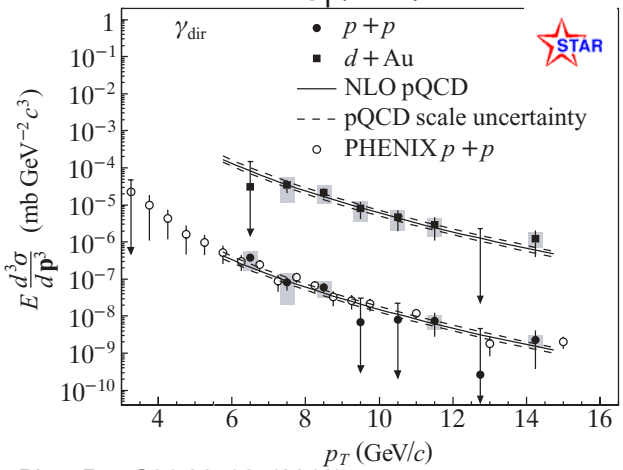
$$A\exp(-p_T/T)+T_{AA}\times A_{pp}(1+p_T^2/b)^{-n}$$

Exponential part **Binary-scaled p+p result**

Centrality	dN/dy ($p_T>1$ GeV/c)	T (MeV)	χ^2/DOF
0–20%	$1.50\pm0.23\pm0.35$	$221\pm19\pm19$	4.7/4
20–40%	$0.65\pm0.08\pm0.15$	$217\pm18\pm16$	5.0/3
Min. Bias	$0.49\pm0.05\pm0.11$	$233\pm14\pm19$	3.2/4

Direct photon spectra at *d*+Au and *p*+*p*

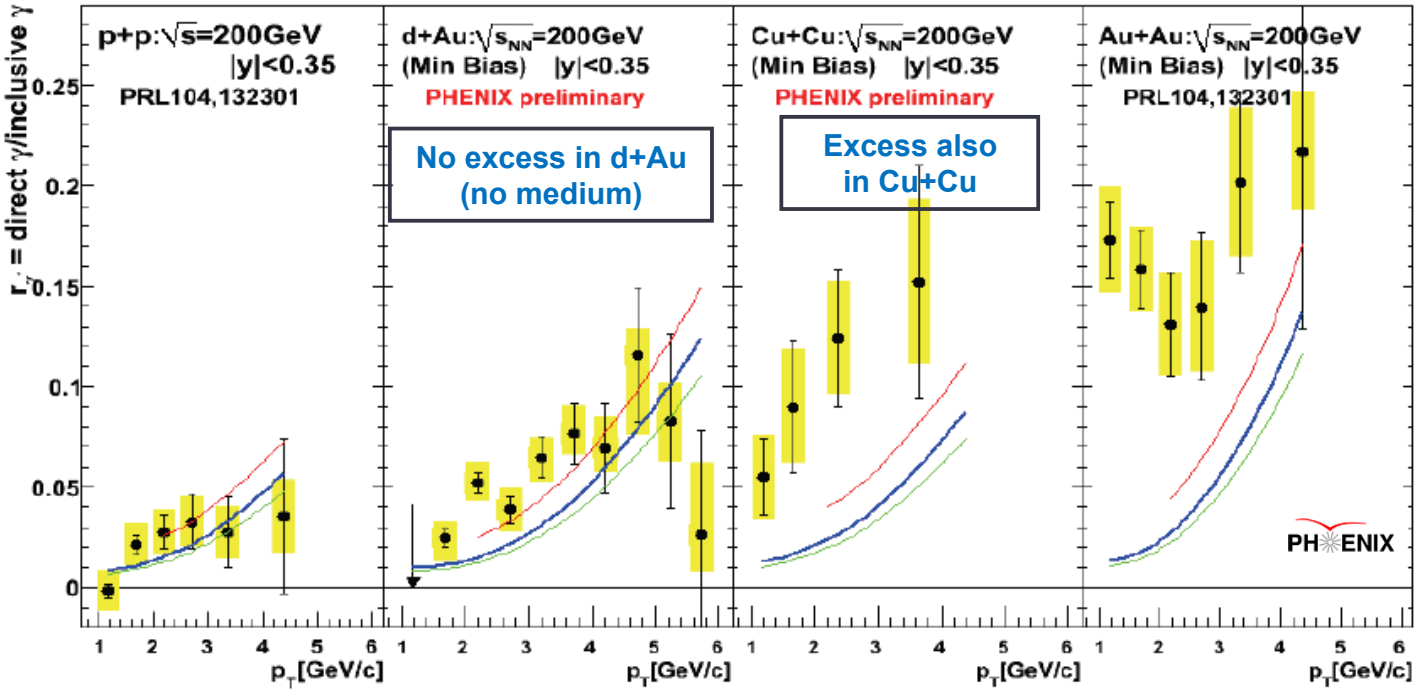




STAR, Phys.Rev.C81,064904(2010)

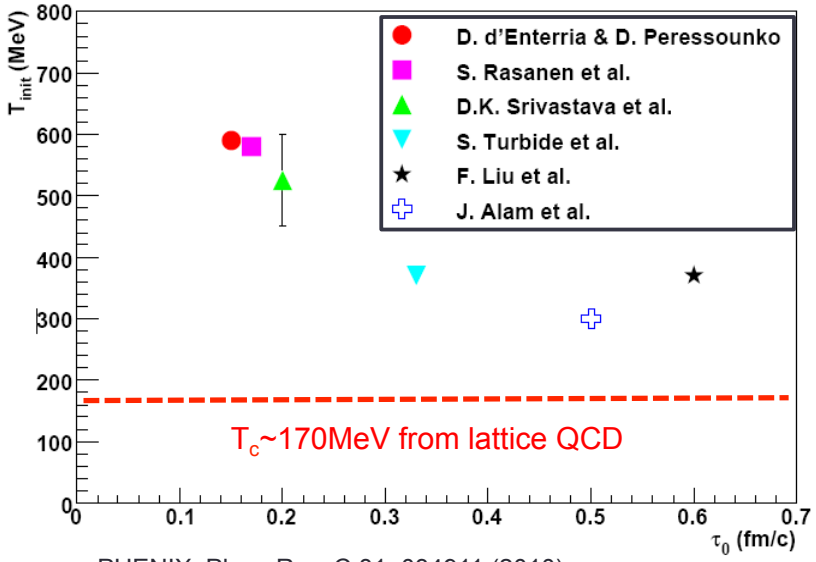
- Excess in *d*+Au?
  - No exponential excess
- High-p_T direct photon results from PHENIX and STAR
  - *d*+Au
    - Agree with T_{AB} scaled pQCD
    - consistent with PHENIX and STAR
  - *p*+*p*
    - Agree with pQCD and PHENIX
- Low-p_T direct photon
  - No publication data at STAR

System size dependence of γ fraction



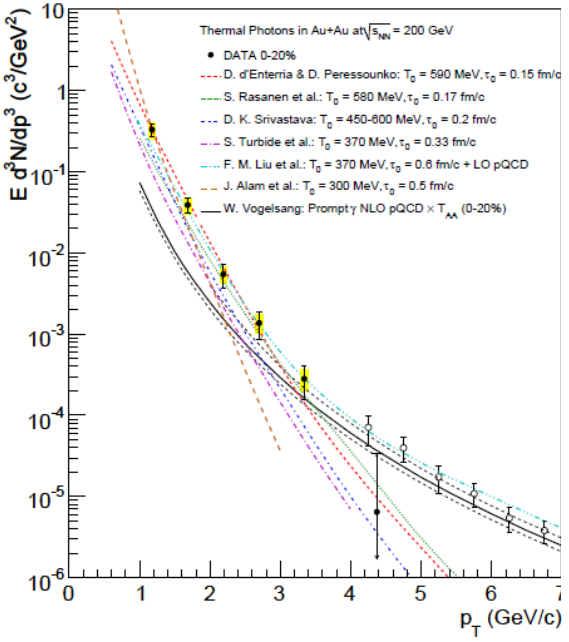
- γ fraction = $\text{Yield}_{\text{direct}}$ / $\text{Yield}_{\text{inclusive}}$
- Largest excess above pQCD is seen at Au+Au.

Initial temperature at Au+Au



PHENIX, Phys. Rev. C 81, 034911 (2010)

- Initial temperature T_i
  - 300 ~ 600 MeV (different assumptions)
  - Depends on thermalization time τ_0

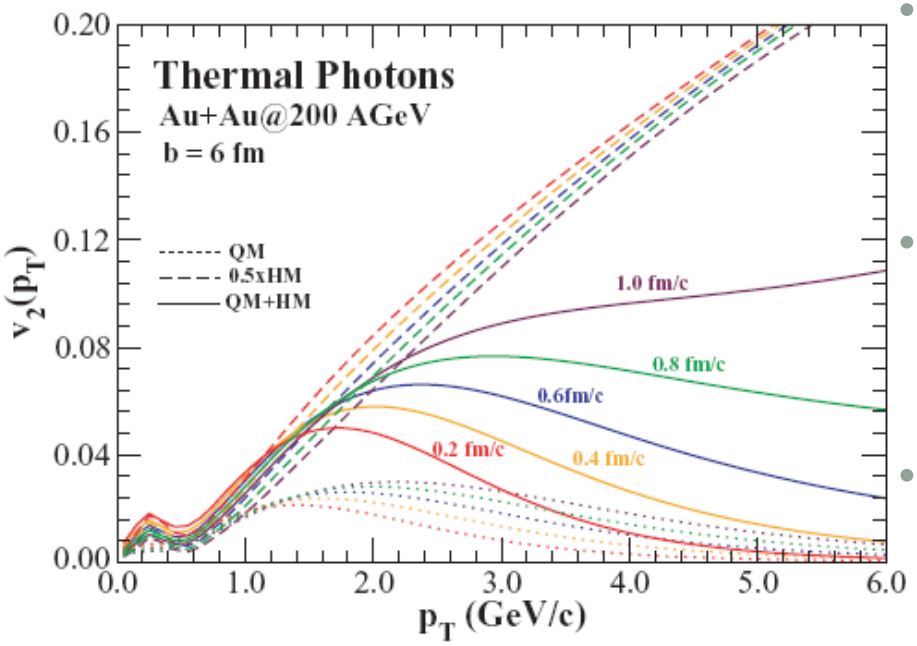


Theory calculations:
d'Enterria, Peressounko, EPJ46, 451
Huovinen, Ruuskanen, Rasanen, PLB535, 109
Srivastava, Sinha, PRC 64, 034902
Turbide, Rapp, Gale, PRC69, 014903
Liu et al., PRC79, 014905
Alam et al., PRC63, 021901(R)

Direct photon v_2

Expectation of direct photon v_2

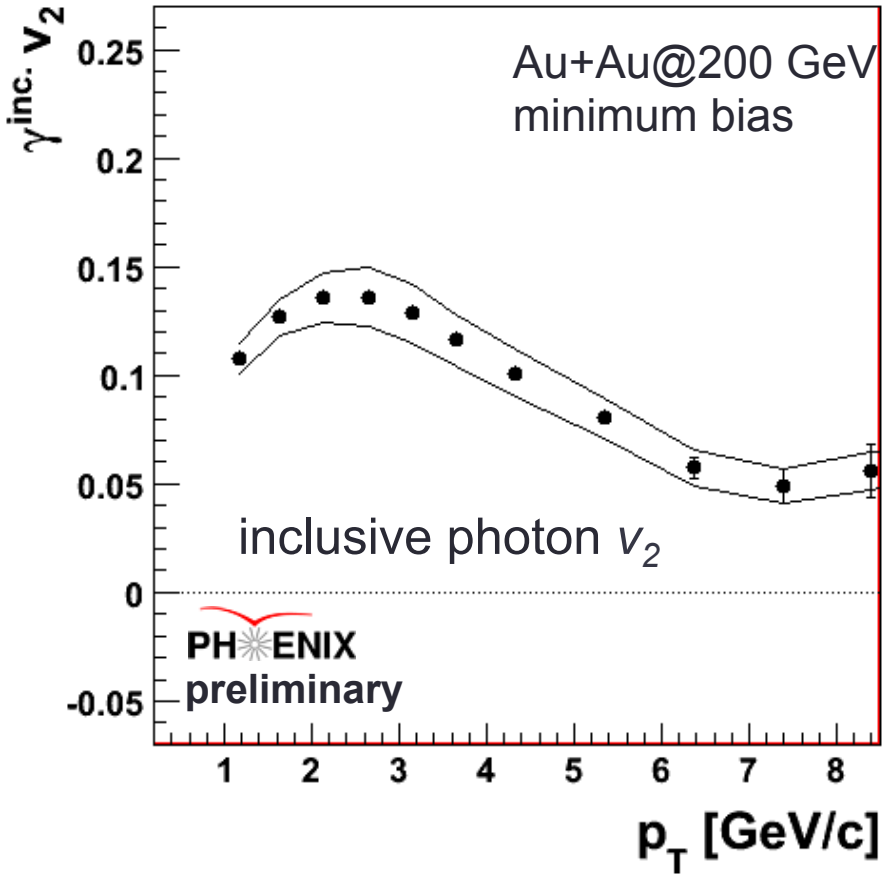
Hydro after τ_0



Chatterjee, Srivastava, PRC79, 021901 (2009)

- Thermal photon in quark matter
  - v_2>0 at low p_T
  - v_2~0 at high p_T
- Thermalization time τ_0
  - Early (smaller v_2)
  - Late (larger v_2)
- Constrain τ_0
  - Measure v_2 at low p_T

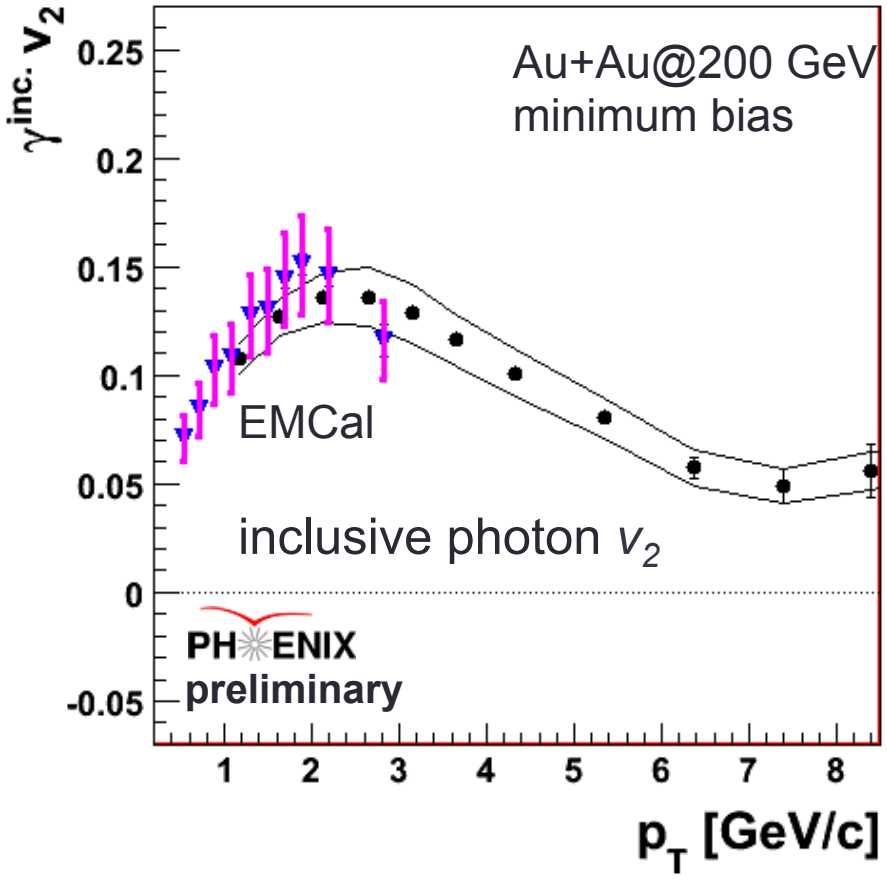
Inclusive photon v_2



Calculation of direct photon v_2
= inclusive photon v_2
- background photon $v_2(\pi^0,\eta, \ldots)$

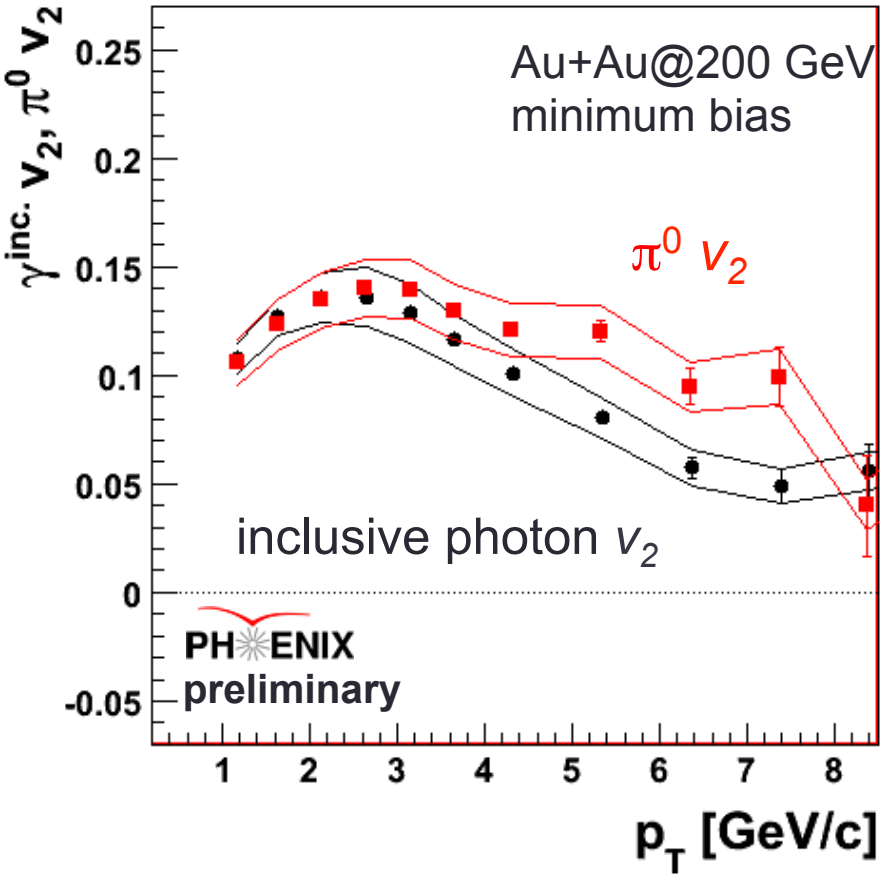
$$v_2^{dir.} = \frac{R_\gamma v_2^{inc.} - v_2^{BG}}{R_\gamma - 1}$$

Check for hadron contamination



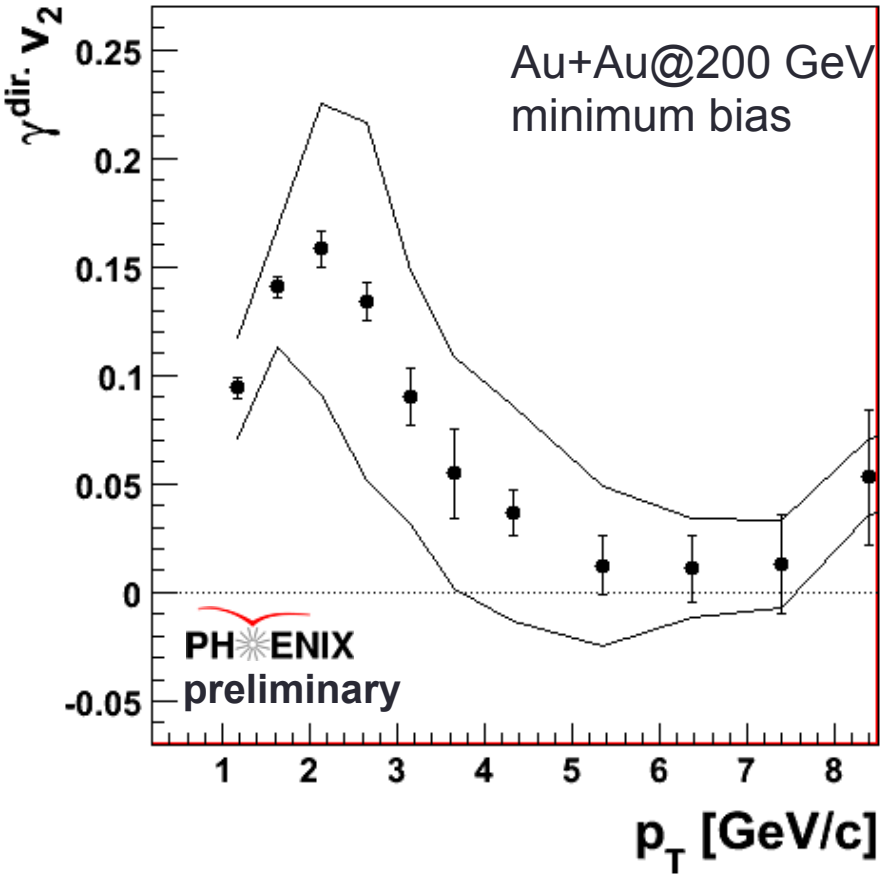
- Direct measurement (black)
  - Identify photons with EMCals
  - Contain hadronic source at low p_T
- External conversions (blue)
  - Identify electron pair ($\gamma \rightarrow e^+e^-$) from gamma conversion
- Good agreement at low p_T
  - **No hadronic contamination**

Inclusive photon and π^0 v_2



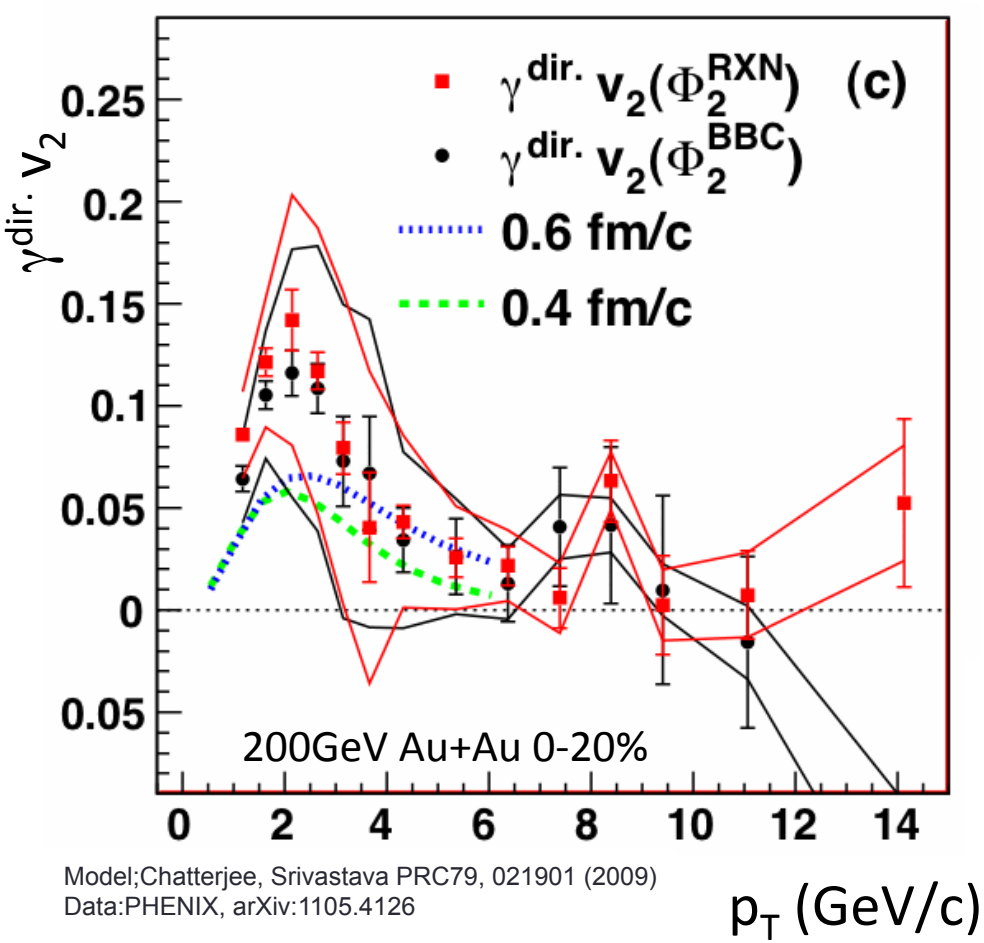
- π^0 v_2
  - similar to inclusive photon v_2
- Two interpretations
  - There are no direct photons
  - Direct photon v_2 is similar to inclusive photon v_2

Direct photon v_2



- v_2 at low p_T
  - ~15% at p_T=2.5GeV/c
- v_2 goes to 0 at high p_T
  - Hard scattered photons dominate

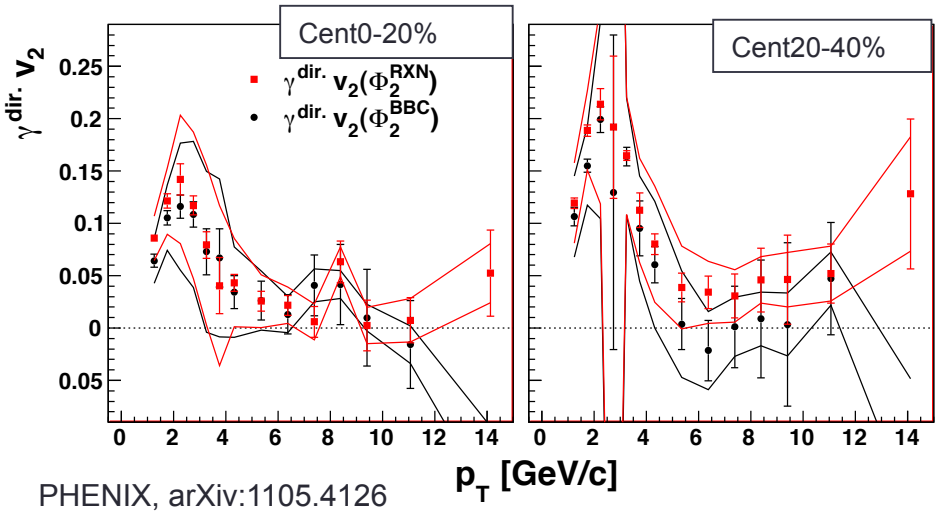
Theory Comparison: Direct photon v_2



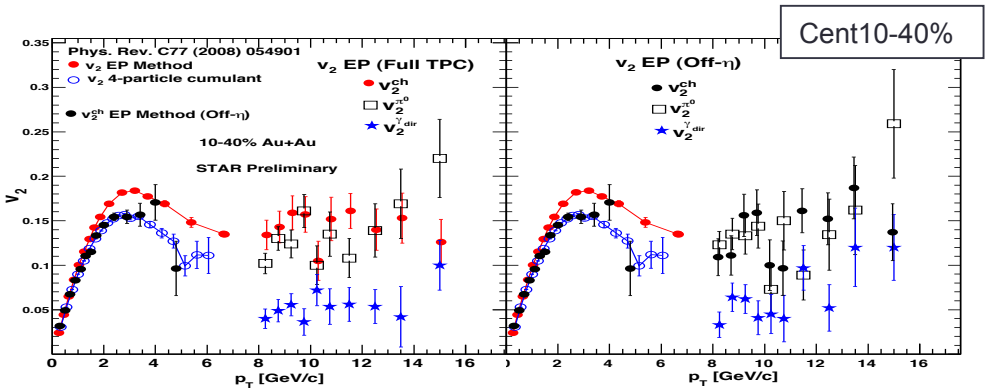
Model;Chatterjee, Srivastava PRC79, 021901 (2009)
Data:PHENIX, arXiv:1105.4126

- Larger v_2 than the prediction
  - Data: ~15% at p_T=2.5GeV/*c*
  - Model: ~5% at p_T=2.5 GeV/*c*
- Need help from theorists
  - There are not any models to reproduce the data
  - To constrain τ_0 with the improved models

Centrality dependence of direct photon v_2



PHENIX, arXiv:1105.4126



STAR, arXiv:1008.4894

- High p_T (p_T>5 GeV/*c*)
  - v_2 ~ 0 (independent of centrality)
  - Consistent with STAR results within large error.
- Low p_T (p_T<3 GeV/*c*)
  - Inconclusive centrality dependence

Summary

- Direct photon yield
  - **Large excess at p_T<3 GeV/*c* (big result at RHIC)**
    - Not initial state effects
  - T_i = 300-600 MeV from hydro calculation
    - Above critical temperature (170 MeV) from lattice QCD calculation
- Direct photon v_2
  - **Large positive v_2 at low p_T(<3 GeV/*c*)**
    - Model underestimates the data
    - We expect the improvement of model to constrain τ_0
  - v_2 ~ 0 at high p_T(>5-6 GeV/*c*)
    - Photons from hard scatterings are dominant source
    - Consistent with the interpretation of direct photon R_{AA}~1

Backups

Systematic error of direct photon v_2

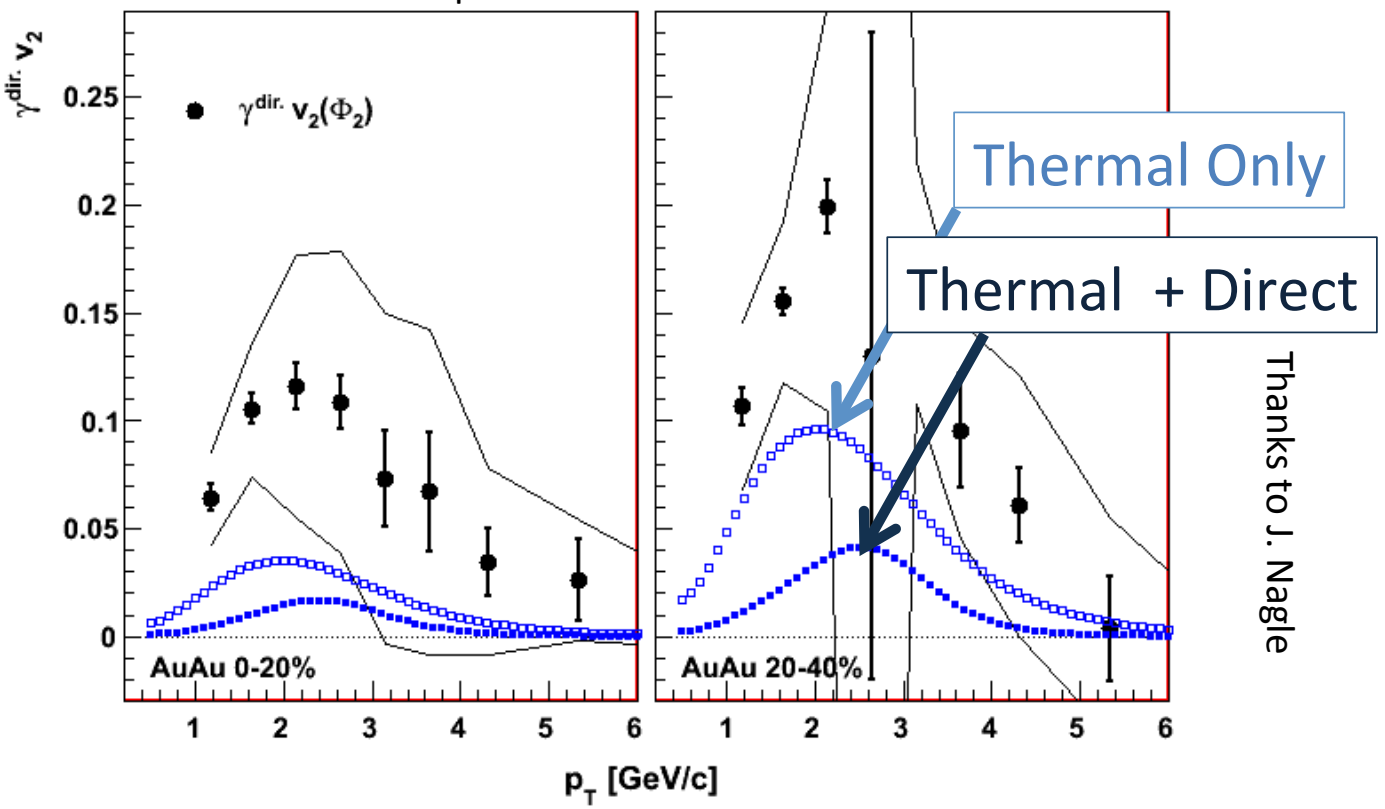
TABLE I: Representative values of systematic uncertainties contributing to the direct photon v_2 measurement, shown for various p_T ranges for minimum bias collisions

Source	1–3ǵeV/c	10–16ǵeV/c	Type
inclusive γ v_2			
remaining hadrons	2.2%	N/A	A
v_2 extraction method	0.4%	0.6%	B
π^0 v_2			
particle ID	3.7%	6.0%	A
normalization	0.4%	7.2%	A
shower merging direct γ	N/A	4.0%	B
R_γ	3.1%	22%	A
common reaction plane	6.3%	6.3%	C

PHENIX, arXiv:1105.4126

Comparison with other models

PHENIX Experiment: arXiv:1105.4126



From Vicki's slide
@ EPIC meeting, Jul.6-8, 2011

Holopainen, Räsänen, Eskola , arXiv:1104.5371v1